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How to support the implementation of Smart Human Resources 4.0 at the enterprise level - the role of leadership and organizational structure

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Abstract

Purpose: This study examines the role of leadership styles and changes in organizational structure within the implementation of Smart Human Resources 4.0 (SHR4.0) as a result of introducing the Industry 4.0 concept. The aim is to examine the role of leadership styles and organizational structure in the success of the Smart Human Resources 4.0 implementation.

Study design/methodology/approach: A questionnaire survey among top managers of companies operating in Slovakia was used to collect data. The PLS-SEM method was used to test the theoretical research model and proposed hypotheses using SmartPLS 3.0 software.

Findings/conclusions: The findings indicate a statistically significant relationship between Industry 4.0 technology solutions and the implementation of Smart Human Resources 4.0 at the enterprise level, which can be strengthened by the inclusion of mediating variables. The two mediating variables of leadership style and organizational structure changes, independently enhance the overall effect, but their joint mediating effect is of substantial importance. Leadership style plays a significant role, with organizational structure being a supporting element in the investigated relationship.

Originality/value: Based on the findings, technology solutions need to be aligned with the human resource development system and supervisors behavior in the new digital culture. In addition to focusing on HR processes, it demonstrates that SHR4.0 transformation process requires capable leaders and a redesign of structures and processes to enable the use of technology.

Limitations and **future research**: Despite the originality of our findings, we acknowledge the limitations of this study, namely its regional focus (on a single country) and the homogeneity of the industry sample. Future research should delve deeper into advanced talent management, workforce planning, and well-being strategies across industries, which are most affected by smart HR 4.0.

Keywords

Industry 4.0, digitalization, human resources, organizational structure, leadership style.

Introduction

The Industry 4.0 (I4.0) paradigm is gaining increasing attention from both the scientific community and practitioners. However, technological solutions alone do not automatically guarantee success (Dabić et al., 2023; Shet & Pereira, 2021). Industry 4.0 means changing the way, time, and space for doing work, which includes a completely new way of thinking. The deployment of digital technologies supports the emergence of new unique competencies (Bissola & Imperatori, 2020; Da Silva et al., 2022; Nešić Tomašević, 2023). In parallel with these developments, a new generation of employees is entering the labor market, bringing new values and expectations (Črešnar, 2020; Sindhuja & Akhilesh, 2020). Thus, the human factor lies behind Industry 4.0 (Galati & Bigliardi, 2019), and its successful implementation also requires a fundamental transformation of human resource management (Gu *et al.*, 2021; Hecklau et al., 2016; Neumann et al., 2021; Pillai & Srivastava, 2024; Verma et al., 2020). The answer may be the concept of Smart Human Resources 4.0 (SHR4.0), which is emerging as a key enabler to effectively connect humans with machines and harness the value derived from it to support societal development (Caratù et al., 2025; Gouda & Tiwari, 2024; Rana & Sharma, 2019; Sivathanu & Pillai, 2018).

While it is now clearly established that the human being is central to the success of digital transformation (Ietto et al., 2024; Neumann et al., 2021), and the concept of SHR4.0 appears to be an essential strategy for success, organizations are still not sufficiently prepared for this reality. They are aware of the need to design workplaces with new technologies in mind and reconfigure work profiles (Ansari et al. 2020; Da Silva et al. 2022; Hecklau et al. 2016; Liboni et al. 2019; Nešić Tomašević, 2023; Neumann et al. 2021; Pillai & Srivastava, 2024) to reach out to talents with specific characteristics, foster their creativity and manage their performance (Ietto et al. 2024; Pillai & Srivastava, 2024; Sivathanu & Pillai, 2018) and they have been transforming their HR quite successfully in this regard. However, the implementation of AI in HR processes is not fully exploited. HR decisions supported by Big Data analysis, identifying development potential with AI support, and its use in designing personal goals and personalized rewards (Da Silva et al. 2022; Kambur & Yildirim, 2023; Pillai & Srivastava, 2024; Tambe et al. 2019) in practice still lags behind the available options and solutions.

In this context, Da Silva et al. (2022), Kambur and Yildirim (2023), and, Pillai and Srivastava (2024) highlight that AI applications in HRM are still underutilized. Similarly, Tambe et al. (2019) note that AI-supported personalized HR decision-making remains rare in practice. Although the literature (e.g., Galati & Bigliardi, 2019; Gu et al., 2021; Hecklau et al., 2016; Neumann et al., 2021) confirms HR's key role in digital transformation, authors such as Pillai and Srivastava (2024) and Ietto et al. (2024) argue that these insights are not yet fully implemented in managerial practice. Verma et al. (2020) confirm the positive impact of dynamic HR capabilities in Industry 4.0, but detailed mechanisms and interactions remain underexplored. Tambe et al. (2019) and Apascaritei and Elvira (2022) also call for further research into specific success factors and their interrelations. While some studies address organizational change (Fettig et al., 2018; Da Rocha et al., 2022; Stornelli et al., 2021) and leadership in the digital era (Bunjak et al., 2022; Črešnar et al., 2023; Dabić et al., 2023), their combined impact on SHR4.0 implementation remains insufficiently explained. To summarize, although the literature acknowledges the importance of HRM, organizational structure, and leadership in Industry 4.0, a systematic examination of their interrelations and impact on SHR4.0 implementation at the organizational level is lacking. Our study addresses this gap through empirical testing of a model analyzing these relationships.

Based on the above, we can conclude that the research-confirmed recognition of the importance of HR as a key factor for successful digital transformation is not yet fully applied in management practice. On the contrary, managers often declare the unpreparedness of HR for current needs. Formulating clear practices that can be implemented to support SHR4.0 at the enterprise level is therefore desirable. There is a need to theoretically explore the factors that determine the success of SHR4.0 and to understand their interrelationships and interaction.

The success of SHR4.0 implementation at the level of organizations rests on the shoulders of their managers. An element of novelty in our study is precisely looking at the supporting factors in the implementation of the SHR4.0 concept from the perspective of management and its functions. As

we know, the adaptation of leadership styles due to I4.0 has proven to be necessary and affects organizational success. Cultural openness (Elnadi & Abdallah, 2023), fostering innovation (Ali et al., 2024; Cugno et al., 2022; Dabic et al., 2023; Hadi et al., 2024), information sharing (Avwokeni, 2024) and learning support (Bunjak et al., 2022) are essential attributes of leadership. Several studies have also addressed the necessary changes in organizational structure, without which successful implementation of I4.0 is not possible (Doblinger, 2022; Gutierrez et al., 2019). These are modifications to organizational structures (Fettig et al., 2018; García De Soto et al., 2022; Mohiuddin et al., 2023; Shaba et al., 2019), supported by the introduction of agility principles (Bouchard et al., 2022; Petermann & Zacher, 2020; Pfaff, 2023; Rane & Narvel, 2021) and self-managed teams (Doblinger, 2022; Gutierrez et al., 2019).

Thus, there is ample evidence that changes in both functions have a demonstrable impact on the success of an organization in an I4.0 environment (Črešnar et al., 2023; Dabić et al., 2023; García De Soto et al., 2022; Parente et al., 2020; Pfaff, 2023). However, what role they play in the inevitable transformation of SHR4.0 remains unexplored to date. Understanding what role organizational structure and leadership styles play in the successful implementation of SHR4.0, and how they interact with each other, has many important implications for how organizations conceptualize HR. By examining these issues, we will fill an important knowledge gap that will support organizations to be successful in implementing SHR4.0, help them to benefit from its effects, and strengthen their sustainable competitive advantage. In doing so, we will also highlight the challenges that still exist in trying to understand the role of the human factor as key in the context of I4.0 and expand the range of solutions for organizations and their managements.

While many studies examine these factors separately, our findings show that transformational, digital, and agile leadership styles foster a culture of openness and innovation, while flexible organizational design enables practical implementation. Thus, the contribution of our study lies in offering an integrated perspective and practical recommendations for managers aiming to achieve successful digital transformation through SHR4.0.

In line with our intention, the paper investigates the following research questions:

1. How does I4.0 influence the need to transform HRM to the SHR4.0 concept?
2. Which factors at the level of organizations support the transformation of HR to SHR4.0?
3. How can the implementation of SHR4.0 be supported at the organizational level?

The paper is organized as follows: section 1 introduces the reader into the theory of human resource management and explains its transformation due to the impact of industry 4.0, section 2 discusses the methodological approach, section 3 presents the research findings, section 4 discusses the findings in the context of previous research, and section 5 presents the conclusions, including theoretical and managerial implications, limitations of the research, and considerations about its future direction.

1. Theory and Hypothesis development

1. Industry 4.0

The concept of the Fourth Industrial Revolution was introduced in 2011 and later in 2013 it was complemented by recommendations for the implementation of the strategic initiative "Industry 4.0". The essence of I4.0 is the implementation of cyber-physical systems in a manufacturing environment (Liu & Xu, 2017; Lu, 2017; Peruzzini et al., 2017) against the background of smart grid systems (Culot et al., 2020). It is shaped in particular by digitalization and information technology (Klingenberg et al., 2022; Zhong et al., 2017; Müller et al., 2018; Peruzzini et al., 2017), but changes are happening at the physical, digital and biological levels as a result (Liao, 2017).

At the enterprise level, the adoption of I4.0 is associated with the expectation of higher productivity and flexibility (Culot et al., 2020), efficiency (Castelo-Branco et al., 2022; James et al., 2022), sustainability (Bai et al., 2020), more individualized products with short time to market and higher quality (Zhong et al., 2017).

2. Smart Human Resources 4.0

Smart Human Resources 4.0 (SHR 4.0) represents a new concept that is evolving during the fourth industrial revolution and is characterized by the transformation of approaches to the effective management of the next generation of workers as a result of innovations in digital technologies (Gouda & Tiwari, 2024; Alam & Dhamija, 2022; Hecklau

et al., 2016). Human resource management is not immune to the impact of Industry 4.0, quite the contrary. The implementation of I4.0 principles requires businesses to pay increasing attention to human resources, as these are becoming critical factors in operational systems (Neumann et al., 2021). Employers need to adopt a more human-centered approach, perceiving the value of their employees, to effectively manage the transition to the new Industry 4.0 paradigm (Ietto et al., 2024). According to Gu et al. (2021), human resources and innovative technologies are complementary factors, therefore, developing new skills for employees and managers seems to be crucial for the successful implementation of the I4.0 paradigm. In doing so, competencies include not only computer literacy but also readiness for collaboration, quick problem solving and understanding of social relationships in a digital context (Nešić Tomašević, 2023). Table 1 captures the essential SHR4.0 challenges underlying this latent variable in our research.

Table 1 Challenges of Smart Human Resources 4.0

Challenges of SHR 4.0	Studies
Reaching and recruiting talent with specific characteristics	Ietto *et al*., 2024; Pillai & Srivastava, 2024; Sivathanu & Pillai, 2018
Designing jobs with diverse skills and competencies	Ansari et al., 2020; Da Silva et al., 2022; Hecklau et al., 2016; Liboni et al., 2019; Nešić Tomašević, 2023
Use of technology in employee search and selection (apps, Big Data, AI, chatbots)	Da Silva et al., 2022; Kambur & Yildirim, 2023; Pan & Froese, 2023; Pillai & Srivastava, 2024; Tambe et al., 2019
Acclimatizing new employees through augmented reality	Jeske & Olson, 2022; Petrilli et al., 2022; Ybarra, 2023
Identifying employee skill gaps and setting goals through artificial intelligence	Gómez-Martínez et al., 2020; Mer & Virdi, 2023; Sharma et al., 2022
Big data in performance management	Da Silva et al, 2022; Kambur & Yildirim, 2023; Pillai & Srivastava, 2024; Rana & Sharma, 2019; Tambe et al, 2019
Reducing turnover by analyzing staff profiles	Ansari et al., 2020; Da Silva et al., 2022; Hecklau et al., 2016; Liboni et al., 2019; Nešić Tomašević, 2023; Neumann et al., 2021; Pillai & Srivastava, 2024
Virtual education	Rana & Sharma, 2019; Tan et al., 2024; Zajac et al., 2022
Continuous feedback	Hagemann & Decius, 2024; Shet & Pereira, 2021
Retaining staff through new value propositions and internal opportunities	Bissola & Imperatori, 2020; Glaister et al., 2018; Ietto et al., 2024; Sivathanu & Pillai, 2018
Smart IoT-based applications and devices for real-time health monitoring and support	Badri et al., 2018; Kadir & Broberg, 2020; Liboni et al., 2019; Mer & Virdi, 2023,

Source: the authors

Several researches confirm that SHRM 4.0 contributes to organizational performance (Apascaritei & Elvira, 2022; Pillai & Srivastava, 2024). Through the development of dynamic human resource capabilities, their performance increases (Tambe et al., 2019; Verma et al., 2020), which has a direct impact on increasing productivity, reducing costs and maintaining competitive advantage (Verma et al., 2020).

Relationship between I4.0 and SHR4.0

Implementation of SHR 4.0. is essential to meet the challenges of Industry 4.0 (Verma et al., 2020). Human resources play a key role in the transformation, as they can be a support but also a barrier to the implementation of I4.0 (Sharma et al., 2022). For example, HR departments may act as barriers by failing to adopt agile processes, resisting data-based decision-making, or lacking digital competencies. On the other hand, HR can enable digital transformation by developing adaptive leadership skills, supporting continuous learning, and redesigning job roles for future competencies (Hecklau et al., 2016; Liboni et al., 2019; Nicolás-Agustín et al., 2022). The onset of digitalization is changing the way people work, learn, manage, and interact with each other (Da Silva et al., 2022). It brings about a change in roles and required competencies of employees (Nešić Tomašević, 2023). Thus, the digital trends resulting from Industry 4.0 are significantly affecting the HRM field in different directions. Based on the above, we formulate the following research hypothesis:

H1: Industry 4.0 (I4.0) technologies are positively related to Smart HR 4.0 (SHR4.0).

3. Organizational structures

The success of implementing new technologies in I4.0, increasing the productivity of organizations, is contingent on the adoption of complementary non-technological changes. Such changes include, according to the findings of several studies, the transformation of organizational structures (Agarwal et al., 2023; Agostini & Filippini, 2019; Črešnar et al., 2023). Digital transformation places great pressure on businesses in the form of demands on their flexibility, agility, and innovative capabilities. At the same time, changes in organizational structure involve both changes in the organization of processes and the organization of work (Fettig et al., 2018). Acknowledging and accommodating the growing complexity not only

in technological dimensions but also in organizational structures has emerged as a pivotal factor for the effective implementation of the Industry 4.0 paradigm (Da Silva et al., 2022; Gama & Magistretti, 2023). While some authors use the term "organizational change" broadly, we refer more precisely to "organizational structure," which includes variables mentioned in table 5 and other structural aspects, like team autonomy, decentralization, and flattening of hierarchies. These are core attributes that enable the successful implementation of SHR4.0 in an Industry 4.0 environment. As shown in Table 2, the identified transformations in OS include flat structures, prevalence of teamwork, virtual and agile teams, decision-making at lower levels, and decentralization of authority and knowledge (Fettig et al., 2018; Chowdhury & Murzi, 2020; Kumar et al., 2022; Kannengiesser, 2023). These features directly support faster decision-making and a more dynamic response to innovation needs.

Table 2 Changes in the organizational structure of enterprises in the context of Industry 4.0

Changes in organizational structure	Studies
Flat organizational structure	Fettig et al., 2018; García De Soto et al., 2022; Mohiuddin et al., 2023; Shaba et al., 2019
The prevalence of teamwork	Chowdhury & Murzi, 2020; Sten et al., 2024
Virtual teams	Kimura, 2024; Morrison-Smith & Ruiz, 2020; Purvanova & Kenda, 2022
Virtual work from anywhere and everywhere	Freeman et al., 2022; Kumar et al., 2022
Self-management of teams	Doblinger, 2022; Gutierrez et al., 2019; Ryu et al., 2022
Decision-making at lower management levels	Davutoğlu, 2020; Nayernia et al., 2022; Parente et al., 2020; Shamim et al., 2016
Subordinates with more authority, responsibility, and knowledge	Kaasinen et al., 2020; Kumar et al., 2021; Shamim et al., 2016
Strengthened communication networks between management and staff	Eroi et al., 2016; Narula et al., 2020; Taqi et al., 2023
Agile teams	Bouchard et al., 2022; Petermann & Zacher, 2020; Pfaff, 2023; Rane & Narvel, 2021

Source: the authors

Relationship between OS and SHR4.0

Along with technology, people and organizations are also at the heart of Industry 4.0 (Stuss, 2023). In such a situation, human resource systems need to be aligned with the new way of doing work. The need for more flexible work organization and greater connectivity requires the emerging SHR4.0 to support a more direct relationship between employees and the organization (Bissola & Imperatori, 2020). Many organizational changes are taking place directly within HR, new working practices and ways of interacting are being defined, HR departments are being slimmed down, and responsibilities are being decentralized (Huettermann et al., 2024). The performance of remote work, enabled by the increase in digitalization, requires not only new technical, but also organizational solutions. For this work to be effective, a balance must be struck between information technology, organizational tools, and behavioral aspects (De Bruyne & Gerritse, 2018).

Relationship between OS and I4.0

The advent of new technologies is inevitably accompanied by changes in organizational structure, even at the enterprise level. Digital transformation puts great pressure on companies in terms of flexibility, agility, and innovation capacity (Fettig et al., 2018). Fundamental changes in organizational work are occurring to which rigid organizational structures cannot respond with sufficient flexibility. Organizational structure - structures, hierarchies, and processes - must therefore be transformed, as the full benefits of I4.0 cannot be achieved without restructuring organizational processes (García De Soto et al., 2022). Based on the above, we formulate the following research hypothesis:

H2: The relationship between Industry 4.0 (I4.0) and Smart HR 4.0 (SHR4.0) technologies is mediated by the organizational structure (OS) of the enterprise.

4. Leading people in the 4.0 era

For the 4.0 era, there is no clearly defined specific style with proven behavioral characteristics of leaders. Bunjak et al., (2022) even state that new technologies create increasingly perplexing leadership challenges. However, scholars agree that this new technological era requires leaders who are value-driven and possess the capabilities to cope with rapid technological change (Črešnar et al., 2023; Dabić et al., 2023; Hernandez-de-Menendez et al., 2020; Schneider, 2018; Veile et al., 2022). A desired outcome of transforming leadership styles in the 4.0 era is for leaders to understand and respond to the values and practices of the new technological and innovative environment (Dabić et al., 2023; Schneider, 2018; Stouten et al., 2018) that contribute substantially to manufacturing productivity in an I4.0 organizational environment (Črešnar et al., 2023; Dabić et al., 2023). These authors reveal the importance of soft values for productivity

improvement and the role of leaders in this process and point out that organizational results come from capable leaders who facilitate and support processes and structures to use technology in the right way.

Many studies that address the topic of leadership in the 4.0 era describe existing styles (especially the transformational style) enriched with various aspects of innovation and technology orientation, along with the ability to share information, lead in a network, communicate openly, give and receive feedback, and build trust in teams. In Table 3, we theoretically summarize several approaches to change in the managerial function of leading people under the conditions of the fourth industrial revolution, which form the basis for defining this latent variable in our research.

Table 3 Changes in leadership styles in the context of Industry 4.0

Identified changes in leadership styles	Studies
Openness to cultural change with a focus on improving knowledge	Elnadi & Abdallah, 2023; Rüth & Netzer, 2020; Schneider, 2018; Sivathanu & Pillai, 2018
Promoting the introduction of new ideas to increase the innovative strength of the enterprise	Ali et al., 2024; Cugno et al., 2021; Dabić et al., 2023; Erhan et al., 2022; Hadi et al., 2024; Sainger, 2018; Verma & Singh, 2022
Connecting and collaborating between humans and robots	Bader & Kaiser, 2019; Bankins et al., 2024; Goswami et al., 2024; Le et al., 2024; Sarioguz & Miser, 2024
A leadership style that accelerates innovation and learning	Behie et al., 2023; Bosch et al., 2018; Bunjak et al., 2022; Kelly, 2019; Oberer & Erkollar, 2018; Shamim et al., 2016; Turyadi et al., 2023; Yuliza et al., 2024
A leadership style based on information and information sharing	Avwokeni, 2024; Bunjak et al., 2022; Mihardjo et al., 2019; Oberer & Erkollar, 2018; Sikora, 2017; Sivathanu & Pillai, 2018
Leadership style based on continuous knowledge enhancement	Hanschke, 2018; Islam et al., 2017; Mihardjo et al., 2019; Naqshbandi & Jasimuddin, 2018; Nasir & Akhtar, 2019
Rewarding unconventional "out-of-the-box" thinking in the workforce	Bolte et al., 2018; Sivathanu & Pillai, 2018
Eliminating conflicts between multi-generational groups of workers	Camberos, 2023; Fotso, 2024; Sivathanu & Pillai, 2018
Using an agile approach	Akkaya, 2020; Ghamrawi et al., 2024; MacIntyre, 2017; Organa & Sus, 2023; Şahin & Alp, 2020

Source: the authors

Relationship between LS and SHR4.0

All the leadership changes identified above are directed toward people and their management in the 4.0 era, which must be adapted to this phenomenon. All HR functions in the 4.0 era should be smart. The implementation challenges of the HR4.0 smart concept are not only about breaking down technological barriers (Sivathanu & Pillai, 2018), but more importantly the support of leaders with the values and capabilities of the technological era is needed. Only the latter has the potential to transform complex HR processes (Dabić et al., 2023).

Relationship between LS and I.4.0

A result of the implementation of Industry 4.0 aspects is not only technological changes and innovations (Bunjak et al., 2022b; Castagnoli et al., 2020; Hamidi et al., 2018; Marcucci, 2021; Muhuri et al., 2019), but also the transformation of managerial functions, including leadership. Many authors argue that new technologies do not automatically guarantee the success of a firm (Bunjak et al., 2022b; Dabić et al., 2023; Shet and Pereira, 2021) and that other factors, particularly affecting human interactions, are equally important (Črešnar et al., 2023; Yang et al., 2020). At the same time, these factors, in the form of soft skills, can remove barriers that hinder the adoption of Industry 4.0 technologies (Agostini & Filippini, 2019; Birkel et al., 2019; Dabić et al., 2023; Dalenogare et al., 2018). Leadership style is thus not only a contextual variable, but a key enabler of digital transformation. Organizational agility is considered a foundational element for survival in this era. This includes styles such as transformational leadership, innovation-oriented leadership, agile leadership (Cutter Consortium, 2017; Şahin & Alp, 2020), digital leadership (Avwokeni, 2024), and shared leadership (Bunjak et al., 2022). Each of these styles emphasizes different but complementary capacities such as technology facilitation, empowerment, adaptation, and communication. Leadership changes in this era enable and increase the leader's influence on the adoption of IT innovations in the organization (Bunjak et al., 2022).

H3: The relationship between Industry 4.0 (I4.0) and Smart HR 4.0 (SHR4.0) technologies is mediated by manager leadership style (LS).

H4: The relationship between Industry 4.0 (I4.0) and Smart HR 4.0 (SHR4.0) technologies is mediated by the firm's organizational structure (OS) and the manager's leadership style (LS) simultaneously.

Based on the above, we formulate the research model of our study, which is shown in Figure 1.

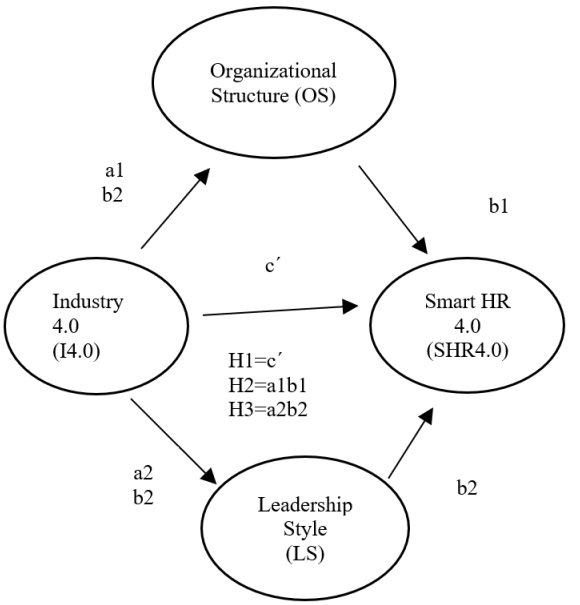

Figure 1 Research model of the study
Source: the authors

2. Design/methodology/approach

We used a questionnaire survey to collect data. Before launching the survey, we conducted validation of the instrument with managers of 5 enterprises. In face-to-face meetings, the content of the questionnaire was consulted to ensure its quality. These were Solved Ltd., Perry Talents, OLO a.s., ČSOB Stavebná sporiteľňa a.s., and the New Generation Bory Hospital, which apply Industry 4.0 principles to some extent and have experience with Management 4.0. In this way, we ensured 2 main components of instrument validation and face and content validity. Within face validity, the experts mainly examined the clarity, appropriateness, logical context, format of the questionnaire items, and its overall structure, including response options. In terms of content, the experts assessed key aspects, namely the relevance, representativeness, and comprehensiveness of the questionnaire items for the construct, or the possible redundancy or overlap of items. We also carried out preliminary testing of the questionnaire with managers of 4 large industrial companies HYDAC Electronic s.r.o., LEYARD EUROPE s.r.o., Muehlbauer Technologies s.r.o., Schüle Slovakia s.r.o., who confirmed the understanding of all questions of the questionnaire (Colbert et al., 2019; Willimack et al., 2023) and enriched our knowledge with personal experiences from their practice.

In the subsequent questionnaire survey, mostly top managers of industrial enterprises in Slovakia were contacted via LinkedIn services and by email communication. We contacted 3,061 managers of such enterprises, based on the Finstat portal database, which aggregates registration, financial and legal data on Slovak and Czech companies and sole traders from dozens of sources. We performed a simple probability sampling (every tenth enterprise) after filtering out enterprises with 50 or more employees. We assumed the application of Management 4.0 tools in these enterprises. Anonymity was ensured by not specifying the name of the company. At the same time, the email message contained an initial introduction to the meaning and purpose of the research, instructions for completing the questionnaire, the time required to complete it, and a notification that by returning the completed questionnaire the respondent agrees to the processing of data. A link to the questionnaire was attached. The entire survey was conducted between March and April 2023. The final research sample consisted of 115 responses. Although the overall response rate was low, we consider the collected data to be relevant and informative due to the extensive number of in-depth personal consultations conducted with managers. These consultations provided qualitative insights and ensured that the participating managers were both highly engaged and motivated to contribute, which supports the credibility and contextual validity of the responses despite the limited sample size. The rest of the research sample consisted of mid-level managers. In terms of location of operations, the sample consisted of companies evenly located throughout the country. In terms of managerial level, the majority of respondents were senior managers (87%). The majority of the businesses analyzed (57%) had 100% foreign participation. The remainder consists of domestic enterprises (33%) and enterprises with a majority foreign participation (10%).

Common method bias

Since our data for all variables (independent, dependent, and mediating) were collected using the same method, they are subject to bias (Podsakoff et al., 2012). To avoid common method bias as much as possible, we implemented as many corrective measures as possible, especially procedural ones,

which are more beneficial in cases where the data cannot be re-collected (Podsakoff et al., 2012). These include clarifying the aim of the research and providing clear instructions to respondents, as well as ensuring understanding of the items by both removing double meanings and brief explanations, avoiding redundancy, and using reverse-coded items. We have also deliberately used negative wording of items for variables because, according to (Dueber et al., 2021) they "disrupt the patterns" of this trap and require a higher focus on the questionnaire items. At the same time, we visually separated the dependent, independent variable, and mediator items in the questionnaire and by using the identification section. Using the VIF indicator, whose values were less than 5.0 (Hair et al., 2019), we found that the model is not subject to collinearity and can be considered free of common method bias.

Operationalization and Measurements

The 4 latent variables have been the subject of the research.

The Industry 4.0 (I4.0) variable has many definitions. Our study adopts the Boston Consulting Group's multidimensional definition of I4.0 ("Industry 4.0", n.d.), based on which the construct is made up of 9 items representing the different technologies implemented within I4.0. It is a formative construct, where our observed variables that make up the construct also cause it (Ringle et al., 2020). Managers scored the degree of implementation for each item using a Likert scale of 1 (none) to 6 (high).

The SmartHR 4.0 (SHR4.0) variable contains 19 items identifying the essence of HRM in the 4.0 era. The items are taken from the author's conceptual model (Sivathanu & Pillai, 2018) - 12 items and supplemented with additional items that we identified from the authors' studies (Table 1).

Managers scored the level of agreement for each item using a Likert scale of 1 (strongly disagree) to 6 (strongly agree).

The variable Organizational Structure (OS) contains 9 items identifying the essence of organizational structure in the 4.0 era. The items are taken from the author's conceptual model (Sivathanu & Pillai, 2018) - 2 items and supplemented with additional items that we identified from the authors' studies (Table 2).

Managers scored the level of agreement for each item using a Likert scale of 1 (strongly disagree) to 6 (strongly agree).

The Leadership Style (LS) variable contains 9 items identifying the essence of leadership styles in the 4.0 era. The items are taken from the author's conceptual model (Sivathanu & Pillai, 2018) - 2 items and supplemented with additional items that we identified from the authors' studies (Table 3). Managers scored the level of agreement for each item using a Likert scale of 1 (strongly disagree) to 6 (strongly agree).

Table 4 Latent variable categories and descriptors - I4.0 and HRM

KP	Industry 4.0 technologies (I4.0)	AP
I4.0_1	Additive manufacturing	2,69
I4.0_2	Augmented reality	2,38
I4.0_3	Autonomous robots	2,88
I4.0_4	Big Data and Analytics	3,21
I4.0_5	Cloud computing	3,23
I4.0_6	Cyber Protection	4,18
I4.0_7	Horizontal and vertical integration	3,22
I4.0_8	Internet of Things	3,20
I4.0_9	Simulations	3,30
KP	**Identified changes in human resource management (SHR4.0)**	**AP**
SHR4.0_1	Reaching and recruiting talent with specific characteristics	3,56
SHR4.0_2	Designing jobs with diverse skills and competencies	3,40
SHR4.0_3	Posting job offers on smart/mobile apps	3,30
SHR4.0_4	Automated CV search using AI and Big Data	2,30
SHR4.0_5	Automated customized testing of candidates	2,10
SHR4.0_6	Real-time remote video interviewing on a fast data network	3,71
SHR4.0_7	Chatbots with artificial intelligence interpret and verify candidate responses in real time	1,66
SHR4.0_8	Acclimatizing new employees through augmented reality	1,79
SHR4.0_9	Identifying worker skills gaps through artificial intelligence	1,70
SHR4.0_10	Using artificial intelligence to set individual worker goals	1,63
SHR4.0_11	Rewards based on Big Data	1,86
SHR4.0_12	Motivating and supporting worker creativity	4,08
SHR4.0_13	Reducing turnover by analyzing staff profiles	2,66
SHR4.0_14	Identifying low-performing workers based on Big Data	3,56
SHR4.0_15	Virtual training anytime, anywhere	3,20
SHR4.0_16	Continuous feedback	3,41
SHR4.0_17	Retaining staff through new value propositions and internal opportunities	3,34
SHR4.0_18	Not promoting staff based on KPIs instead of seniority	3,72
SHR4.0_19	Smart IoT-based applications and devices for real-time health monitoring to reduce sick leave	1,93

Source: own elaboration

Note: AP - Arithmetic mean of I4.0 implementation rate (1- none, 6 - high), respectively Arithmetic mean of agreement rate with statements for items SHR4.0 (1- strongly disagree to 6 - strongly agree); KP= variable codes

Table 5 Latent variable categories and descriptors OS and LS

KP	Identified changes in organizational structure (OS)	AP
OS_1	Flat organizational structure	4,20
OS_2	The prevalence of teamwork	4,68
OS_3	Virtual teams	2,95
OS_4	Virtual work from anywhere and everywhere	3,38
OS_5	Self-management of teams	3,84
OS_6	Decision-making at lower management levels	4,03
OS_7	Subordinates with more authority, responsibility, and knowledge	3,77
OS_8	Strengthened communication networks between management and staff	4,06
OS_9	Agile teams	3,54
KP	**Identified changes in leadership styles (LS)**	**AP**
LS_1	Openness to cultural change with a focus on improving knowledge	3,97
LS_2	Promoting the introduction of new ideas to increase the innovative strength of the enterprise	3,99
LS_3	Disconnection and collaboration between humans and machines	3,87
LS_4	A leadership style that accelerates innovation and learning	3,88
LS_5	Data-driven leadership style	4,03
LS_6	Leadership style based on continuous knowledge development	4,21
LS_7	Rewarding unconventional "out-of-the-box" thinking in the workforce	3,55
LS_8	Eliminating conflicts between multi-generational groups of workers	3,91
LS_9	Using an agile approach	3,79

Source: own elaboration

Note: AP - Arithmetic mean of agreement rate with statements for items OS, LS (1- strongly disagree to 6- strongly agree); KP= variable codes

Data analysis

Data analysis was performed using the PLS-SEM method (partial least squares structural equation modeling) (Hair et al., 2019) with SmartPLS 3.3 software. That method allows multiple hypotheses to be tested simultaneously under both direct and indirect effects in a complex system (Becker et al., 2018). It is used when samples are relatively small, the research model is complex, the focus of the study is on predicting dependent variables, and when latent variable scores are used for predictive purposes (Roldán & Sánchez-Franco, 2012). We evaluated the measurement model and the structural model. We used all the available tools of this software to verify the reliability and validity of the model. Hypotheses were statistically tested at a significance level of $\alpha = 0.05$.

3. Conclusion

Measurement model

The evaluation of the first model provides data on the fulfillment of all the common requirements of the model. Individual reliability is confirmed by calculating standardized external variable loadings, which in our model range from 0.555 to 0.944 and, according to (Götz et al., 2009), are considered acceptable. Internal construct reliability was monitored through Cronbach's alpha (values found to range from 0.741 to 0.898), composite reliabilities (CR) (values found to range from 0.837 to 0.929), and rho_A (values found to range from 0.759 to 0.912), all of which were greater than 0.70 and less than 0.95 (Hair et al., 2019) and at the same time, based on theory, rho_A should be between the Cronbach's alpha and CR (Ringle et al., 2020). We assessed the convergent validity by calculating the average variance extracted (AVE), which in our model exceeds the level of 0.5 (Hair et al., 2019) for all constructs, meaning that the construct explains an average of at least 50% of its item´s variance (values ranging from 0.524 to 0.814).

The next step was to assess discriminant validity. We assessed the model according to the heterotrait-monotrait correlation (HTMT) ratio (Ringle et al., 2020), which is measured as the mean value of the indicator correlations across constructs. Since not all values are below 0.9 (Henseler et al., 2015), we applied cross-loading because of the validation of the loading of indicators into latent variables. The results of the analysis indicate that if the cross-loading is applied, a particular indicator should have a higher loading on its latent variable than on the other latent variables in the study (Henseler et al., 2015). Based on the above, discriminant validity is established. We no longer needed to use the Forner-Larcker criterion.

Structural model

When analyzing a structural model, it is important to assess the R2 (R-squared) value of endogenous indicators, as the stringency of each structural path is determined by the R2 value and identifies the goodness of the model. The R2 value of the variables in our model was in the range of 0.273 to 0.621, indicating that the predictive capability is established since the results are higher than 0.1. (Hair Jr et al., 2017). A Q2 above 0 shows that the model has predictive relevance. The results (ranging from 0.279 to 0.631) show that there is significance in the prediction of the constructs.
Furthermore, the model fit was assessed using SRMR. The value of SRMR was 0.095. SRMR values should be less than or equal to 0.100, indicating an acceptable model fit (Hair Jr et al., 2017).

Path coefficients and mediating effects

Prior to conducting the mediation in SmartPls software, we conducted a correlation analysis, which shows that all the examined relationships are statistically significant and there are significant positive correlations between the examined variables. In particular, a significant dependence exists for the variable HR and I4.0. Based on the analysis, we can conclude that the implementation of the Industry 4.0 concept is strongly correlated with changes in the managerial function of human resource management, Kendall's tau b=0.612. The coefficient of Eta has a value of 0.855, which represents a very strong correlation.

The next step was to assess the direct and indirect relationships of all latent variables by comparing the β values by testing for their significance level using a t-value test. A nonparametric bootstrapping technique was used. The authors (Hair et al., 2019) state acceptable t-values for a two-sample test of 1.96 at the significance level = 5% with a significant correlation. The results of the effects are presented in the table below.

Table 6 Direct effects, standard deviation, t-value, and p-value

Paths of variables	Original Sample (β)	Sample Mean (β)	Standard deviation	T-value	P-value
I4.0 -> OS	0.529	0.536	0.061	8.722	0.000
I4.0 -> LS	0.574	0.576	0.069	8.313	0.000
I4.0 -> SHR4.0 (H1)	0.490	0.490	0.079	6.180	0.000
LS -> SHR4.0	0.384	0.382	0.105	3.658	0.000
OS -> SHR4.0	0.022	0.029	0.094	0.238	0.812

Source: the authors

The results indicate the existence of significant dependencies for four of the five direct relationships examined that enter into mediation. I4.0 has a significant effect on OS (β=0.529, t=8.722, p<0.05), also I4.0 on LS (β=0.574, t=8.313, p<0.05), I4.0 on SHR4.0 (β=0.490, t=6.180, p<0.05), thus confirming Hypothesis 1. The pathway from LS to SHR4.0 is also significant (β=0.384, t=3.658, p<0.05). All direct effects variables show T-values greater than 1.96 and P-values less than 0.05 (significance level = 5%), with only one case between the OS pathway and SHR4.0 (β=0.022, t=0.238, p>0.05), suggesting a non-significant relationship. As reported by (Hayes, 2022), statistical significance of paths "a" and "b" is not a condition for mediation according to current thinking. Therefore, we conduct the mediation analysis.

Table 7 Direct, indirect, and total mediation effects through the OS and LS variables

Paths of latent variables	Type of effect	Original Sample (β)	Sample Mean (β)	Standard deviation	T-value	P-value
I4.0 -> OS	Direct effects	0.527	0.532	0.066	7.981	0.000
I4.0 -> SHR4.0		0.573	0.580	0.074	7.727	0.000
OS -> SHR4.0		0.294	0.291	0.076	3.874	0.000
I4.0 -> OS -> SHR4.0 (H2)	Specific indirect effects	0.155	0.153	0.041	3.812	0.000
I4.0 -> SHR4.0	Total indirect effects	0.155	0.153	0.041	3.812	0.000
I4.0 -> SHR4.0	Overall effects	0.728	0.733	0.051	14.398	0.000
Direct, indirect and total mediation effects through the variable LS						
Paths of latent variables	**Type of effect**	**Original Sample (β)**	**Sample Mean (β)**	**Standard deviation**	**T-value**	**P-value**
I4.0 -> LS	Direct effects	0.573	0.579	0.071	8.091	0.000
I4.0 -> SHR4.0		0.505	0.507	0.086	5.870	0.000
LS -> SHR4.0		0.388	0.390	0.082	4.708	0.000
I4.0 -> LS -> SHR4.0 (H3)	Specific indirect effects	0.223	0.225	0.053	4.215	0.000
I4.0 -> SHR4.0	Total indirect effects	0.223	0.225	0.053	4.215	0.000
I4.0 -> SHR4.0	Overall effects	0.728	0.732	0.053	13.824	0.000
Direct, indirect and total mediation effects through OS and LS variables simultaneously						
Paths of latent variables	**Type of effect**	**Original Sample (β)**	**Sample Mean (β)**	**Standard deviation**	**T-value**	**P-value**
I4.0 -> LS	Direct effects	0.574	0.574	0.075	7.696	0.000
I4.0 -> OS		0.529	0.533	0.066	7.955	0.000
I4.0 -> SHR4.0		0.490	0.495	0.077	6.406	0.000
LS -> SHR4.0		0.384	0.384	0.103	3.741	0.000
OS -> SHR4.0		0.022	0.022	0.094	0.239	0.811
I4.0 -> LS -> SHR4.0	Specific indirect effects	0.221	0.222	0.070	3.131	0.002
I4.0 -> OS -> SHR4.0		0.012	0.011	0.050	0.236	0.814
I4.0 -> SHR4.0	Total indirect effects	0.232	0.232	0.051	4.570	0.000
I4.0 -> SHR4.0	Overall effects	0.723	0.727	0.050	14.318	0.000

Source: the authors

For the first mediation through the OS variable, all relationships found are significant, with the total effect being β= 0.728 and the indirect effect being β= 0.155, indicating that the mediating effect of OS within the I4.0 -> SHR4.0 relationship is 21.3%, and the direct relationship is 78.7%.

For the second mediation through the LS variable, all relationships found are significant, with the total effect β= 0.728 and the indirect effect β= 0.223, indicating that the mediating effect of LS within the I4.0 -> SHR4.0 relationship is 30.6%, and the direct relationship is 69.4%.

In the third mediation jointly across the OS and LS variables, not all relationships found are significant. The total effect and indirect effect are β= 0.728 and β= 0.232, respectively, and they are significant, indicating that the joint mediating effect of LS and OS in the I4.0 -> SHR4.0 relationship is 32.1%, and the direct relationship is 67.9%. However, only the LS variable is significantly involved in the indirect effect (β= 0.221). The mediation effect of the OS variable is not significant.

Discussion

Our study aimed to further investigate how changes in OS and LS, from managers' perspectives, support the implementation of the SHR4.0 concept, which has become essential for the success of digitalization with the advent of I4.0. Based on the results, we were able to confirm a positive association between the implementation of Industry 4.0 technologies and Smart HR 4.0. This finding is in line with previous studies (Da Silva et al., 2022; Nešić Tomašević, 2023; Sharma et al., 2022), but its verification in the setting of our study extends its validity. The direct effect of the examined relationship is significant (β = 0.490, t =6.180, p < 0.05), indicating that the implementation of I4.0 triggers the need for direct changes in the concepts of human resource management at the level of organizations. We agree with Whysall et al. (2019), that the speed of technological change as a result of the advent of Industry 4.0 has created a significant gap between current workforce capabilities and rapidly evolving demands of tasks, prompting the need to consider new and more effective approaches to human resource development. Consequently, the pressure exerted on its adaptation is immense. The new competencies include not only computer literacy but also the readiness to collaborate, to solve problems quickly, and to understand social relations in a digital context (Nešić Tomašević, 2023). For this reason, it is necessary to make learning and development opportunities available to employees that equip them with the required skills and competencies (Cucculelli et al., 2022). Working with talent becomes an essential part of SHR4.0 (Pillai & Srivastava, 2024; Sivathanu & Pillai, 2018), work environment adaptation (Badri et al., 2018; Liboni et al., 2019), transformation of cultures (Bissola & Imperatori, 2020; Glaister et al., 2018; Ietto et al., 2024) or working with data analytics and Big data (Da Silva et al. 2022; Kambur & Yildirim, 2023; Pillai and Srivastava, 2024). The need to align leadership styles to the SHR4.0 concept as a result of I4.0 is acknowledged. However, the real implementation rate of SHR4.0 elements is at a lower level compared to the expectations of technological advances (see Table 5 for the arithmetic mean of implementation). Therefore, the question arises how this process can be supported at the enterprise level. Our intention was to explore the role of the management functions of organizing and leading people in this context.

Our hypothesis that the relationship between Industry 4.0 (I4.0) and Smart HR 4.0 (SHR4.0) technologies is mediated by changes in organizational structure is confirmed. We agree with the assertion of Agarwal et al. (2023), that Industry 4.0 is characterized by technological disruption and business reorganization. The implementation of I4.0 technologies requires actions that change organizational activities, workplaces, and practices and require the development of new skills and competencies (Cugno et al., 2022). Digitalization enables internal and external stakeholders to share knowledge and collaborate across organizational boundaries, while at the same time increasing their competencies and experiences (Bissola & Imperatori, 2020). The redesign of organizational structures and processes, their decentralization, coupled with the introduction of agile approaches and elements of self-management can help organizations to implement the SHR4.0 concept more smoothly.

Similarly, the hypothesis that the relationship between I4.0 and SHR4.0 technologies is mediated by manager's leadership style was confirmed based on the results of the study. The mediating effect is more intense than that of organizational structure. Our research develops previous findings (Bankins et al., 2024; Bunjak et al., 2022; Črešnar et al., 2023; Dabić et al., 2023; Goswami et al., 2024;

Hernandez-de-Menendez et al., 2020), and complements them with the recognition of the role of leadership as an important factor supporting the implementation of the SHR4.0 concept. If organizations want to successfully transform their HRM systems in line with the needs and demands of digitalization, appropriate leadership styles are a defining attribute in this regard. They need to develop leadership styles in their leaders that support the process of innovation and learning (Behie et al., 2023; Yuliza et al., 2024), information sharing (Avwokeni, 2024; Sivathanu & Pillai, 2018) and rewarding non-traditional "out-of-the-box" thinking by employees (Bolte et al., 2018; Bouchard et al., 2022; Pfaff, 2023).

Since organizations are complex holistic systems where individual processes do not occur in isolation but are integrated, we also verified the assumption that the relationship between I4.0 and Smart SHR4.0 technologies is mediated by OS and LS simultaneously. This hypothesis was equally confirmed. The overall mediation effect is significant despite the low and insignificant influence of one of the variables, namely OS. Although the effect of OS alone is statistically insignificant (β=0.022; p>0.05), its inclusion in the joint mediation with LS increases the total explained variance of the model. This implies that OS may function as a contextual enabler, which strengthens the influence of leadership style on SHR4.0 implementation in specific organizational conditions. (B + tab.7) If organizations support SHR.40 implementations by modifying structures and processes while implementing a digital culture through capable leaders, the effect of leadership styles is demonstrably more significant. The transformation of leadership styles plays a crucial role here, whereas the impact of organizational change is a supporting factor.

Theoretical implications

Our study contributes to a deeper understanding of the complex structural relationships and the role of LS and OS within the relationship between I4.0 and SHR4.0. It confirms their function as mediating variables that influence this relationship. The results of the study enrich the literature in several ways. First, they support the findings of studies that argue that productivity gains do not come from technology as such (Črešnar et al., 2023; Dabić et al., 2023), but it also requires a transformation of human resources to SHR4.0. The massive adoption of digitalization is changing competency models, focusing on decision-making, cultural and intercultural skills, lifelong learning, interdisciplinary thinking, and problem-solving (Coşkun et al., 2019; Hernandez-de-Menendez et al., 2020). Our findings point to the fact that the success of the SHR4.0 transformation process implies that, in addition to focusing on HR processes, it also requires capable leaders and the redesign of structures and processes to enable the use of technology. The implementation of technological solutions, supported by an appropriate leadership style of leaders, in an environment with its setup, structures, and processes that support digital transformation, increases the chances of companies to succeed.

Secondly, the findings draw attention to the need to align technology solutions with the human resource development system, with the new way of working, with the new quality of employees, and with the behavior of supervisors in the new digital culture. The results show that although organizational solutions and process adjustments play a supporting role, the final effect is significantly more influenced by the leader and his/her leadership style. Agile principles (Bouchard et al., 2022; Pfaff, 2023), self-managed teams (Doblinger, 2022), or decentralizing tendencies (Nayernia et al., 2022) in organizational structure can be a solution to facilitate transformation and support human resource development, but the key role is played by a leader who is value-compatible with the new challenges and has the capabilities to cope with rapid technological changes (Črešnar et al., 2023; Dabić et al., 2023; Veile et al., 2022).

Practical Implications

Several practical implications also emerge from this study. To be successful in implementing I4.0 solutions, organizations need to focus on the human factor in addition to the technology itself. The adaptation and development of human resources play a demonstrably key role (Ietto et al., 2024; Pillai & Srivastava, 2024). Evolving job profiles and employee competencies will be crucial (Ansari et al., 2020; Neumann et al., 2021), accompanied by a stronger focus on talent management (Ietto et al., 2024; Sivathanu & Pillai, 2018) and the strategic use of data analytics (Da Silva et al., 2022; Pillai & Srivastava, 2024). In this area in particular, the HRM of organizations is still lagging behind the possibilities and not fully exploiting the available potential. Employers are advised to adopt three basic strategies. First, focus on creating continuous development programs,

making them accessible to employees and fostering a culture of learning at the workplace (Nešić Tomašević, 2023). The arrival of Generation Z in the labor market with profiles that match Industry 4.0 technologies is an advantage for organizations (Hernandez-de-Menendez et al., 2020).

An appropriate strategy would be to focus on the competencies of leaders, whom, according to the study findings, can significantly increase the effects of SHR4.0 by overcoming the barriers that hinder the adoption of IT innovations (Bunjak et al., 2022) and Industry 4.0 technologies (Agostini & Filippini, 2019; Birkel et al., 2019). Organizations should focus their attention on the selection of leaders and their further development as a strategy to support the implementation of SHR4.0. This factor appears to be a key element based on the findings of the study. In addition to leadership development, it is crucial to align organizational structure with SHR4.0 goals. This includes redesigning workflows for agility, promoting decentralized decision-making, supporting team-based work, and ensuring structural flexibility (Fettig et al., 2018; Petermann & Zacher, 2020). A holistic approach that combines both human and structural elements is more likely to produce a sustainable transformation.

Finally, organizations should continuously assess their SHR4.0 implementation level and use these insights to refine both HR practices and organizational architecture. The supporting role is played by organizational solutions in the form of flat structures with a predominance of teamwork and self-managing teams, decentralization of decision-making, and strengthening of communication networks between management and employees. Based on the findings, these solutions appear to be relatively well-established. However, organizations have not yet fully exploited the opportunities for virtual teamwork, agile solutions, and empowerment at lower levels of management. This is where the potential for new approaches opens up.

Research limitations

Although this study provides valuable insights, it also has certain limitations regarding sample selection and methodological decisions. This is a cross-sectional study where data collection was limited to a one-off questionnaire. A longitudinal study was not possible in this case due to the complexity of the topic, the inability of obtaining responses from the same respondents over time, and the complexity of determining the time interval between data collection stages. We believe that it is the cross-sectional design for a new and complex topic that is appropriate and beneficial. Additionally, the low return rate of 115 responses out of 3,061 contacts (approx. 3.8%) can be considered a limitation. However, this limitation is mitigated by the fact that respondents were mostly top managers (87%) with relevant expertise in I4.0 and SHR4.0 topics, and their participation was confirmed in personal consultations during the pilot phase. Therefore, the quality of responses is prioritized over their quantity, following recommendations in elite sampling methods for complex topics (Willimack & Snijkers, 2013). The study was carried out in the conditions of enterprises operating in the Slovak market, while the geographical limitation and low return in the formation of the research sample may be partly limiting. The sample size of the study was adequate for the current analysis, however, a larger and more diverse sample could increase the credibility of the statistical conclusions. On the other hand, from a regional perspective, the sample covers the whole territory of Slovakia, which could support the generalization of the results to the Slovak business environment. However, given the relevance of the topic and the global nature of the discourse surrounding the implementation of I4.0, we assume that the findings have relevance on a broader scale as well. Future studies could address these limitations by applying mixed methods, such as combining quantitative survey data with qualitative interviews or case studies. Moreover, to better capture causal relationships between I4.0, LS, OS, and SHR4.0, longitudinal or experimental research designs could be implemented. Use of techniques such as dynamic panel modeling or qualitative comparative analysis (QCA) may reveal different configurations of influence and temporal effects.

Although we used several steps to mitigate common method bias, we did not use data collection from a variety of sources and this was due to the high expertise of the topic, which was particularly suited to senior management. Future research can focus on management perspectives on the areas under study and combine these with complementary techniques such as observation, which will strengthen the validity of the findings and allow triangulation of the data. Despite these limitations, our study offers a valuable foundation for future research on the key role of LS in the implementation of I.4 in the context of SHR4.0 development.

Declarations

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. Additional supporting materials or clarifications can also be provided upon inquiry. For any data-related questions, please contact the corresponding author.

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